Washington Laboratories, Ltd.

Minimizing Interference in Dense Packaging Environments

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301-417-0220

Washington Laboratories, Ltd

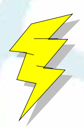
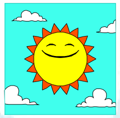
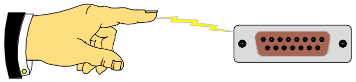
- EMC Design and Control Plans for Commercial, Government and Military Programs
- Aerospace EMC Analysis and Design
- Electromagnetic Pulse Coupling Analysis and Mitigation Design
- Lightning Protection Analysis and Design
- RF Channel Propagation Characterization
- Component Performance and Characterization Testing
- System and Component Failure Analysis
- Standards Development
- RF site surveys
- RF interference abatement studies
- Ordnance hazard studies
- Test and Control plan/procedure development
- Nuclear Power Plant EMC Testing
- Training: Seminars in 1) EMI/EMC Design and Test; 2) Product Safety

Your Presenter

- **Steve Ferguson**

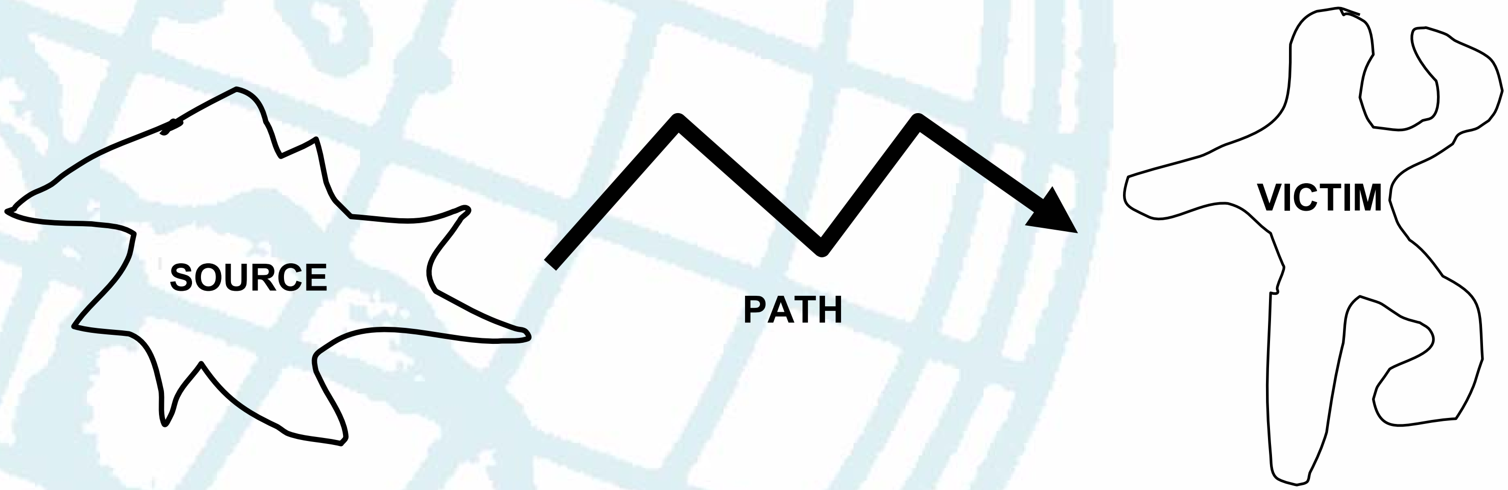
  As the Vice President of Operations, Steve Ferguson is responsible for the day-to-day testing and engineering activities at WLL. He also prepares control plans, test plans and test reports to guide the design from concept to qualification test acceptance for DoD and commercial programs. Steve is a Certified TEMPEST Professional Level II, a Certified Defense Investigative Service Facility Security Officer. He has over 25 years of experience in the EMC/TEMPEST area with prior management positions for commercial electronics manufacturers. Active SECRET security clearance.

EMI – The Problem

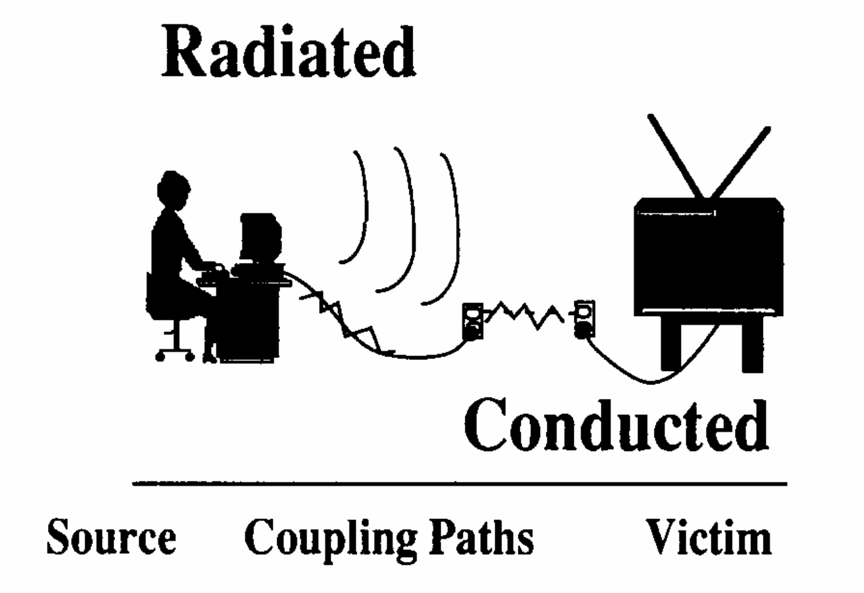
- EMI can occur wherever electrical phenomena are active:
  - Any electrical and electronic device can cause a disturbance (malfunction, degradation, upset, damage) in itself or other electrical/electronic device
- Natural Events
  - Atmospheric,  Solar,  Cosmic  ESD 
- Man Made
  - CW - Transmitters, LOs
  - Pulsed CW - Radars, Beacons,
  - Broadband - Arcing, Narrow pulse, Transients, UWB, CDMA

Elements of an EMI Situation

- Source "Culprit"
- Coupling method "Path"
- Sensitive device "Victim"

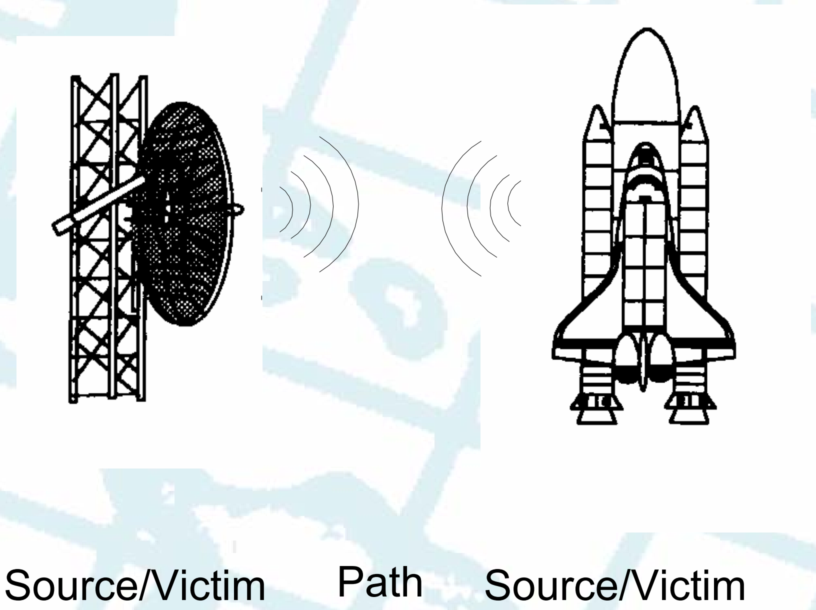


EMI Situation



- Path
  - Conducted (power lines)
  - Radiated (unit, cables)
- Source
  - Computer system
- Victim
  - Television
- Potential inconvenience

EMI Situation



- Path
  - Radiation
- Victim
  - Antenna tower
  - Spacecraft
- Source
  - Antenna tower
  - Spacecraft
- Potential Disaster

EMI Effects

RF Reception
- Annoying noise
- Loss of sensitivity
- Jamming

Data upset
- Data link disruption
- Control signal errors

Power variations
- Power levels outside operating range
- Sense line feedback errors

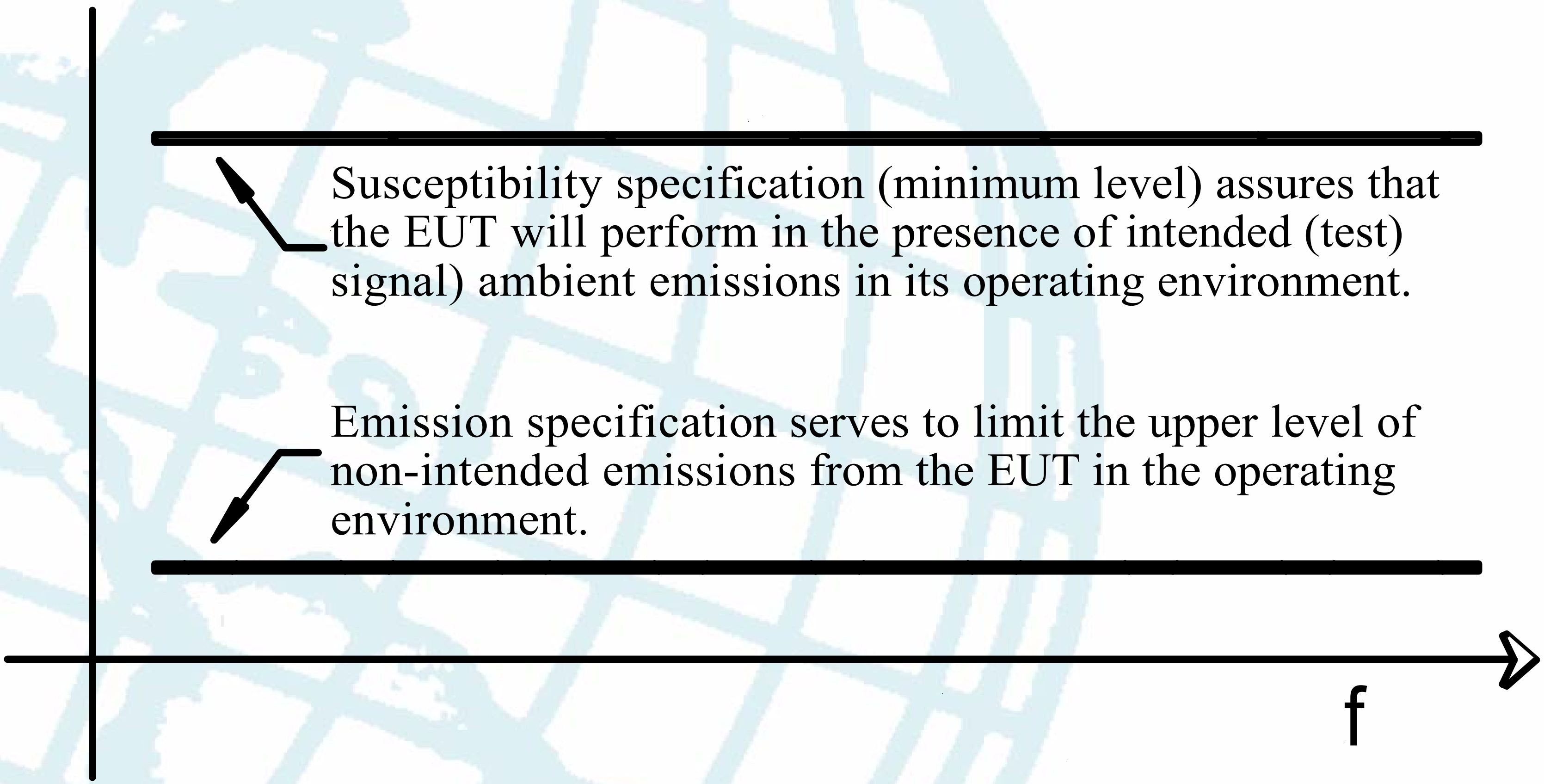
Analog signal errors
- Measurement errors
- Signal-to-noise degradation

Equipment damage
- Circuit malfunction
- Physical damage

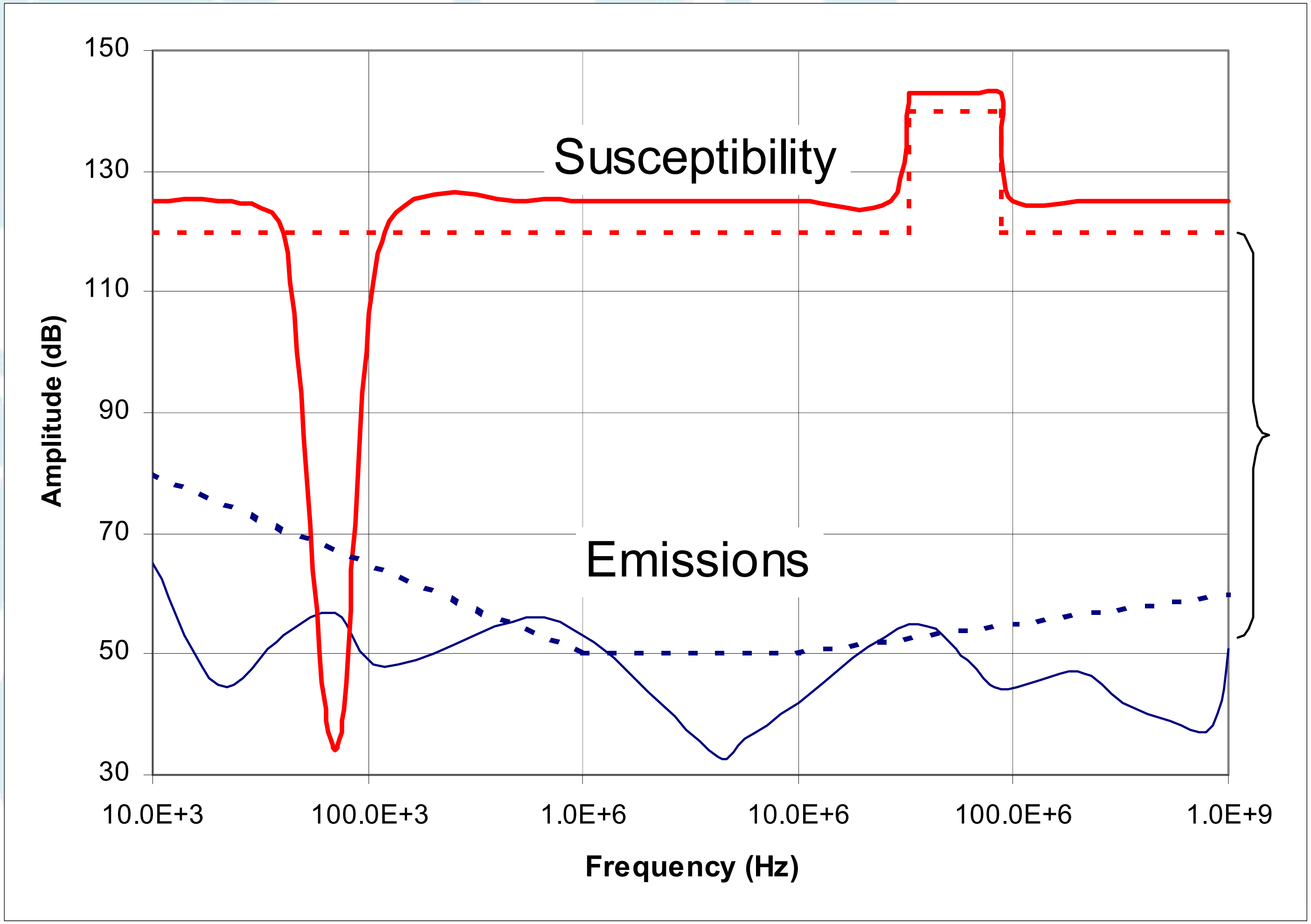
Specifications

- MIL-STD-461
  - Basis for most EMI/EMC compliance evaluations
  - Provides test methods and limits
- DO-160
  - Radio & Technical Committee for Aviation
  - Environmental and EMI/EMC plus Power
- NASA/GEVS
  - General Environmental Vehicular Specifications
  - Based on MIL-STD-461C revision
- Custom specification for specific programs
  - Tailored for environment
  - Tailored for mission

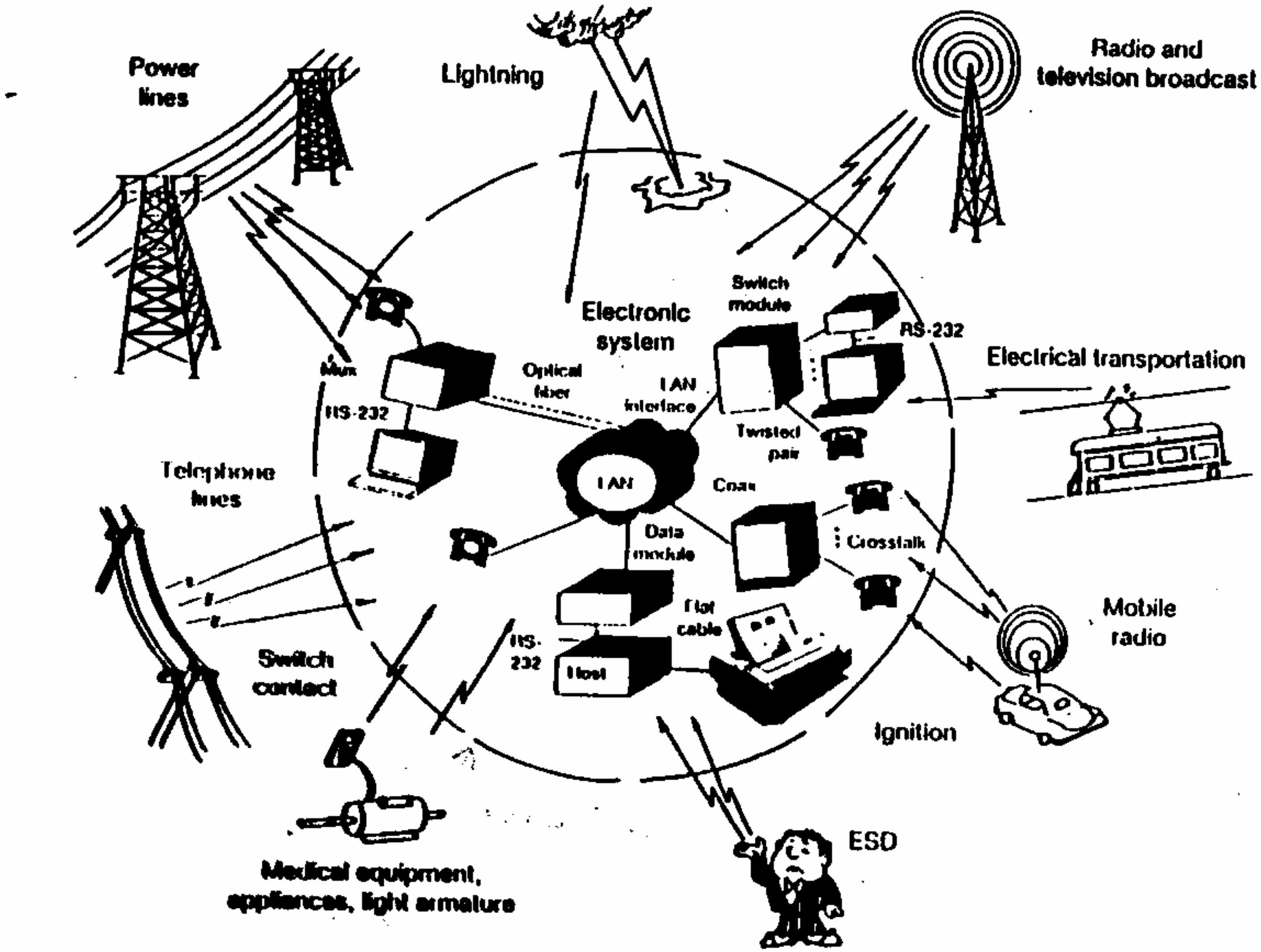
Emission – Susceptibility Specifications



Emissions and Susceptibility

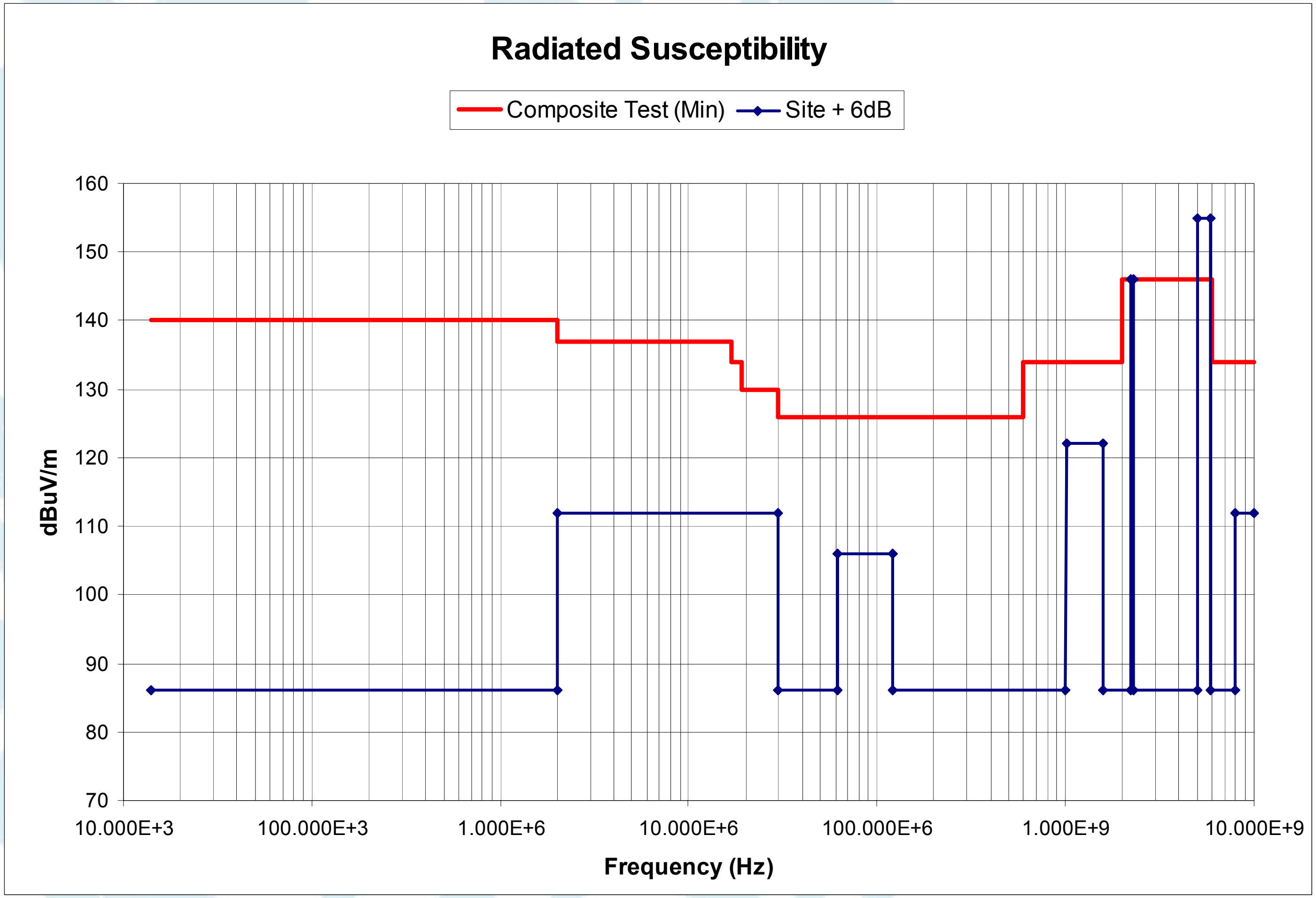


EM Environment



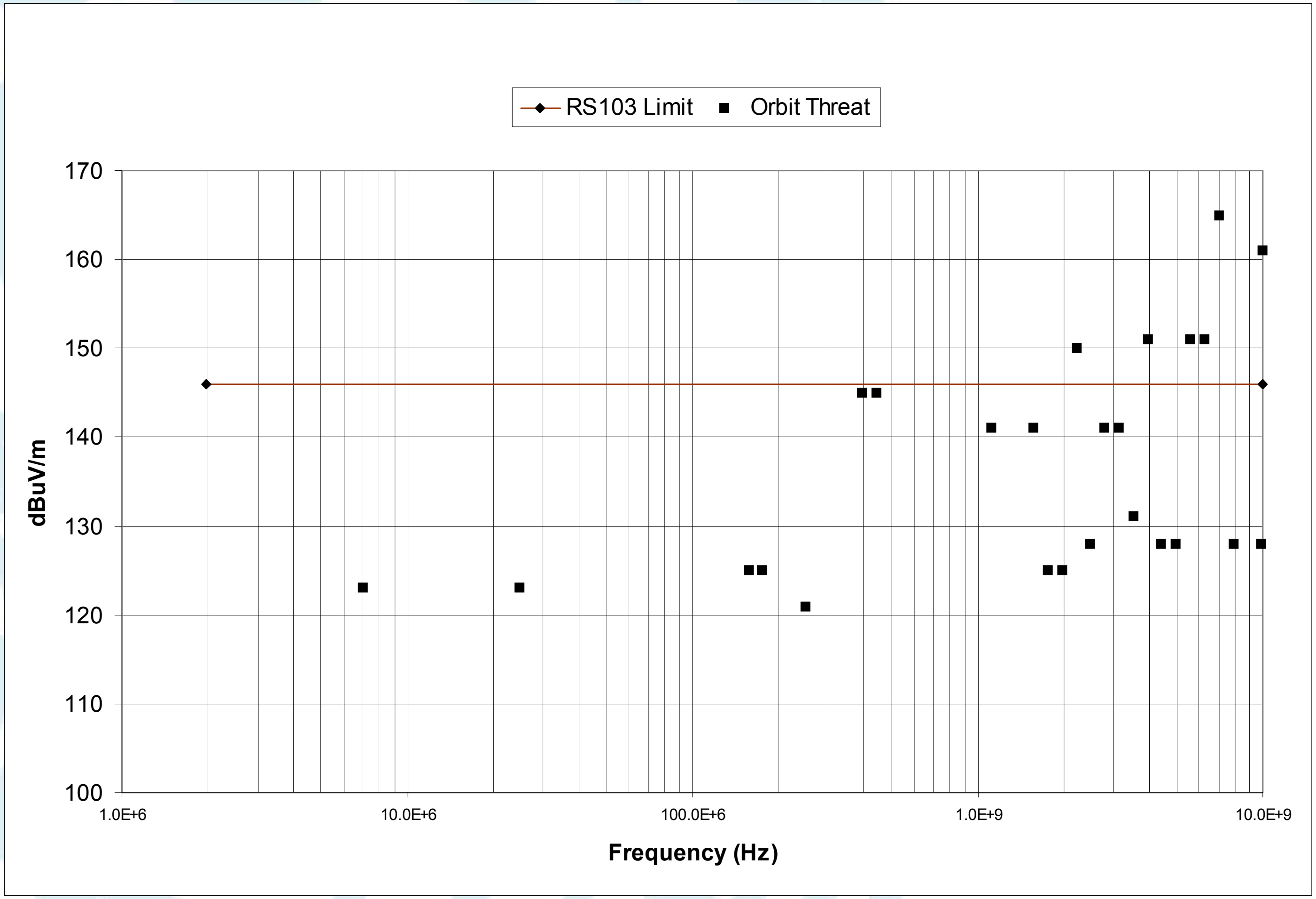
EME – Launch Site

A representative analysis supporting a MSFC program

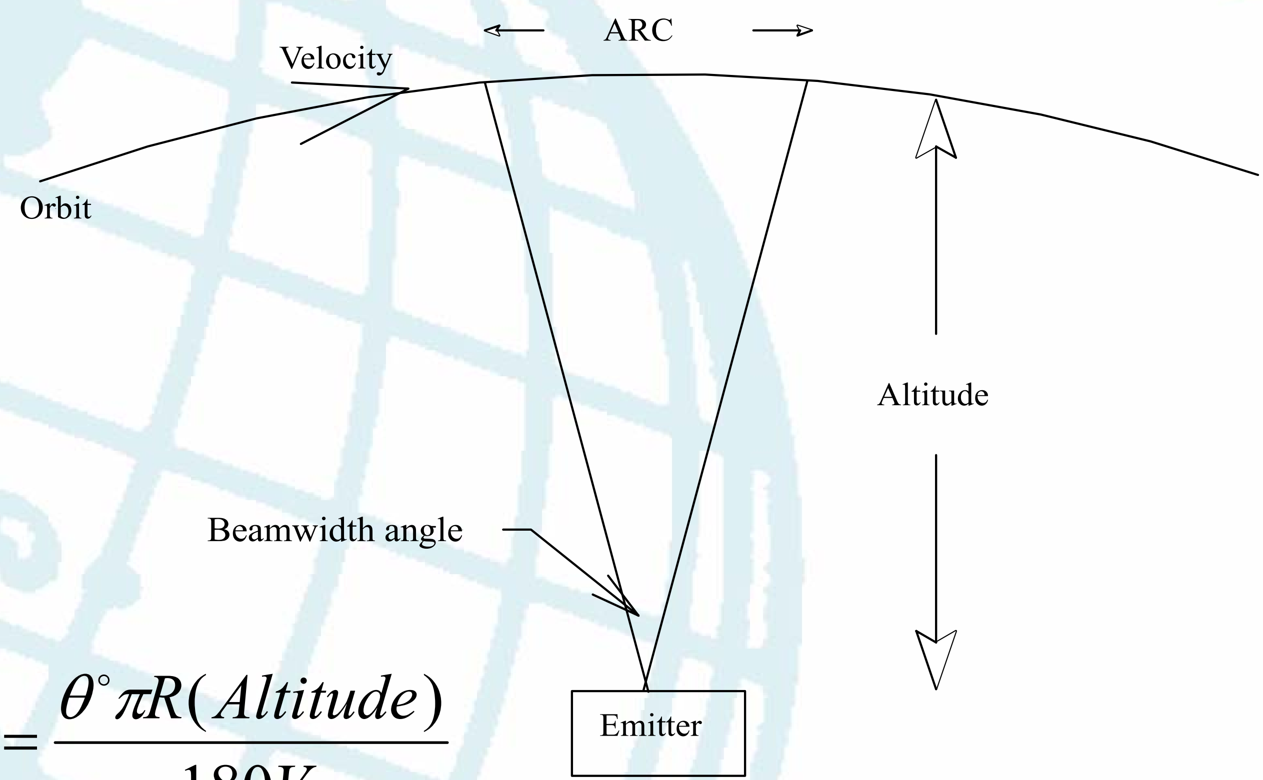


EME – On Orbit

A representative analysis supporting a MSFC program



Time of Exposure



$$TOE = \frac{ARC}{V} = \frac{\theta^{\circ}\pi R(Altitude)}{180V}$$

Where:
- TOE = Time of exposure (seconds)
- R = altitude in miles
- θ = beamwidth in degrees = $\theta\pi/180$ radians
- V = velocity in miles per second

Cables - Loops

- Emissions are a function of 1) Current; 2) Loop Geometry; 3) Return Path of the Current
- Loop geometry formed by the current carrying conductor and the return line contribute to the field strength
- Electric field emission strength approximation:

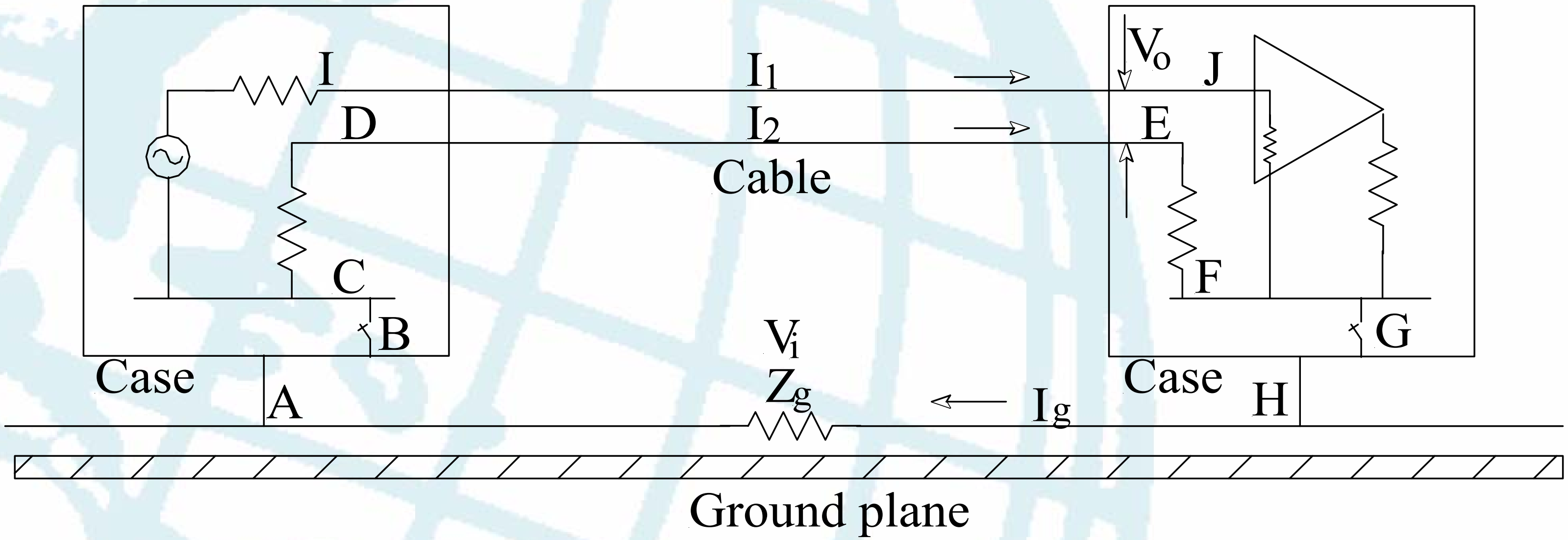
$$E_{V/m} = (1.32\sqrt{1+(\lambda_m/2\pi r_m)^2}(f_{MHz}{}^2/r_m)ANI_{m(f)}$$

λ_m=wavelength
f_{MHz}=frequency in Megahertz
r_m=loop to observer in meters
A=loop area in cm^2
N=number of coincident loops
$I_{m(f)}$=max current at frequency

EMC Coupling Paths

- Conducted
  - Common impedance between two circuits
  - Ground impedance
  - Common signal return path impedance
  - Power line cables
  - Control and interconnecting cables
  - "Bulk" currents induced on enclosures
- Radiated
  - Far-field coupling into cables & wires (antenna coupling), and enclosure apertures
  - Cable-to-antenna, antenna-to-cable coupling
  - Antenna-to-antenna coupling
  - Near-field "crosstalk" inductive and capacitive coupling (cable-to-cable, PCB trace-to-trace)

Common Ground Impedance



Common mode voltage V_i produced by current flow through the ground impedance Z_g

If circuit is case grounded, V_i appears between points C and F in the circuit

This voltage is common to both signal cables causing I_1 and I_2 to flow through unequal Z. This unequal current produces a DM voltage V_o across load terminals

Power Line Coupling

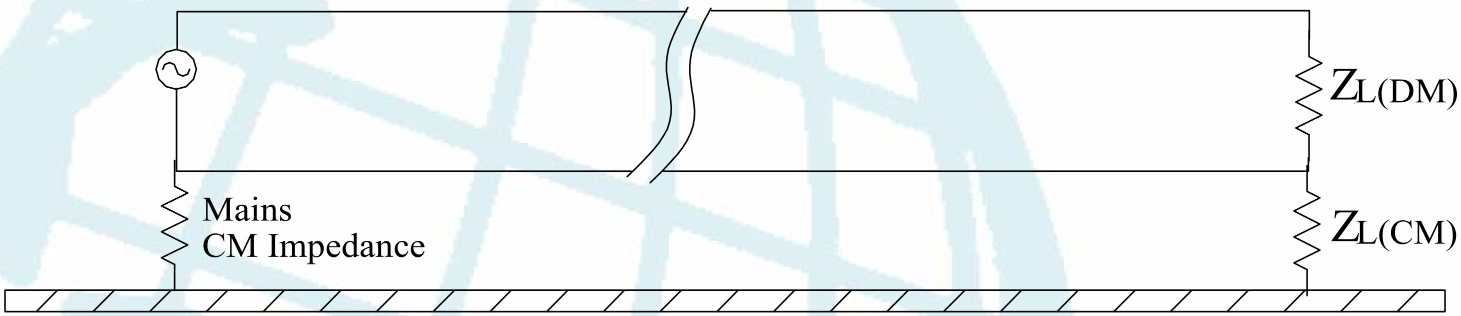


Figure shows a dedicated wire return, however in many configurations the return is via the structure.

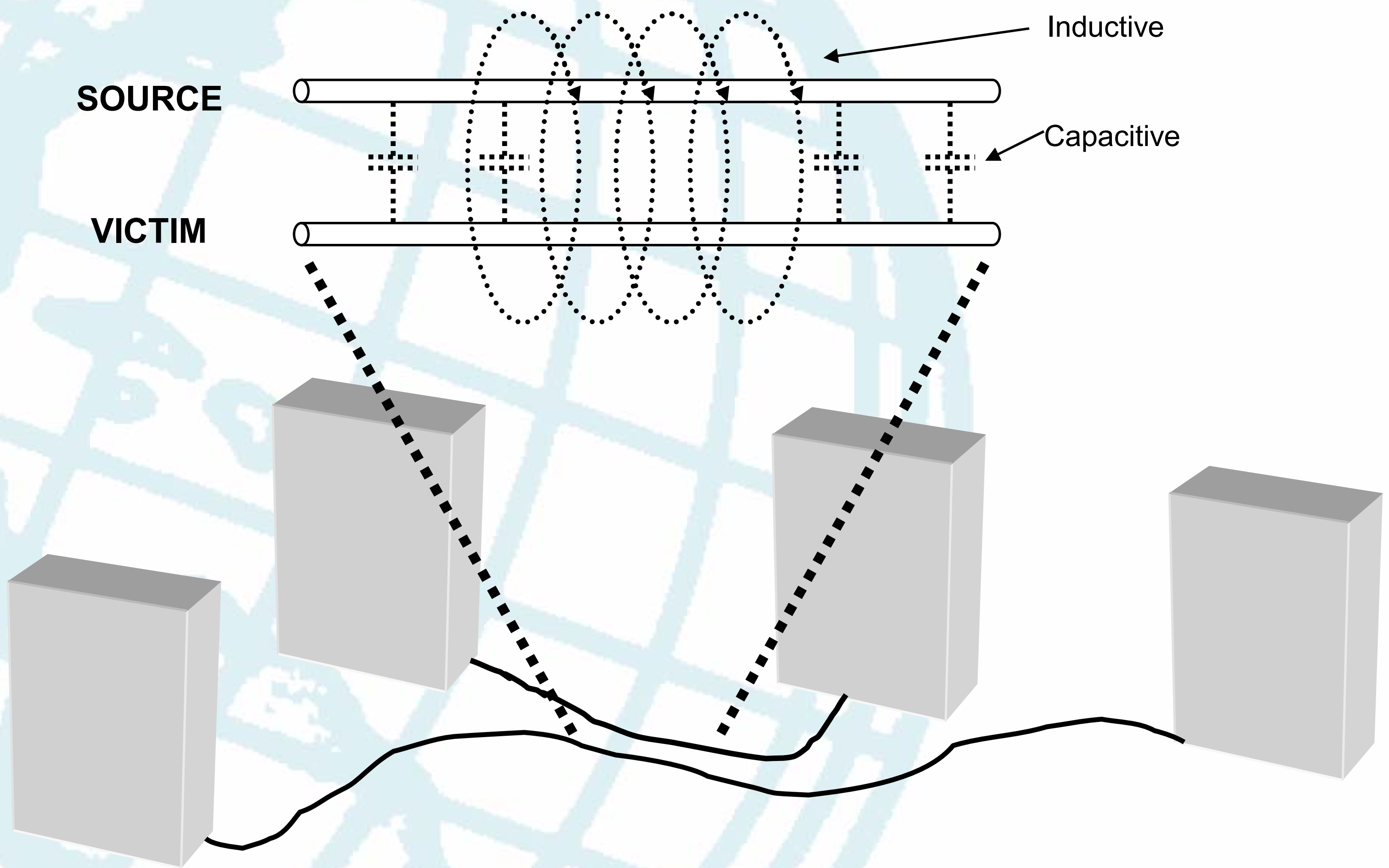
Common mode noise present on power line and return with respect to the ground system (e.g., vehicle chassis). With a chassis return there is no distinction between CM and DM coupling.

With a dedicated return, differential mode noise is present between the power leads and common mode noise is present on both power leads with respect to the structure.

Addition of a safety wire adds a possible CM coupling path.

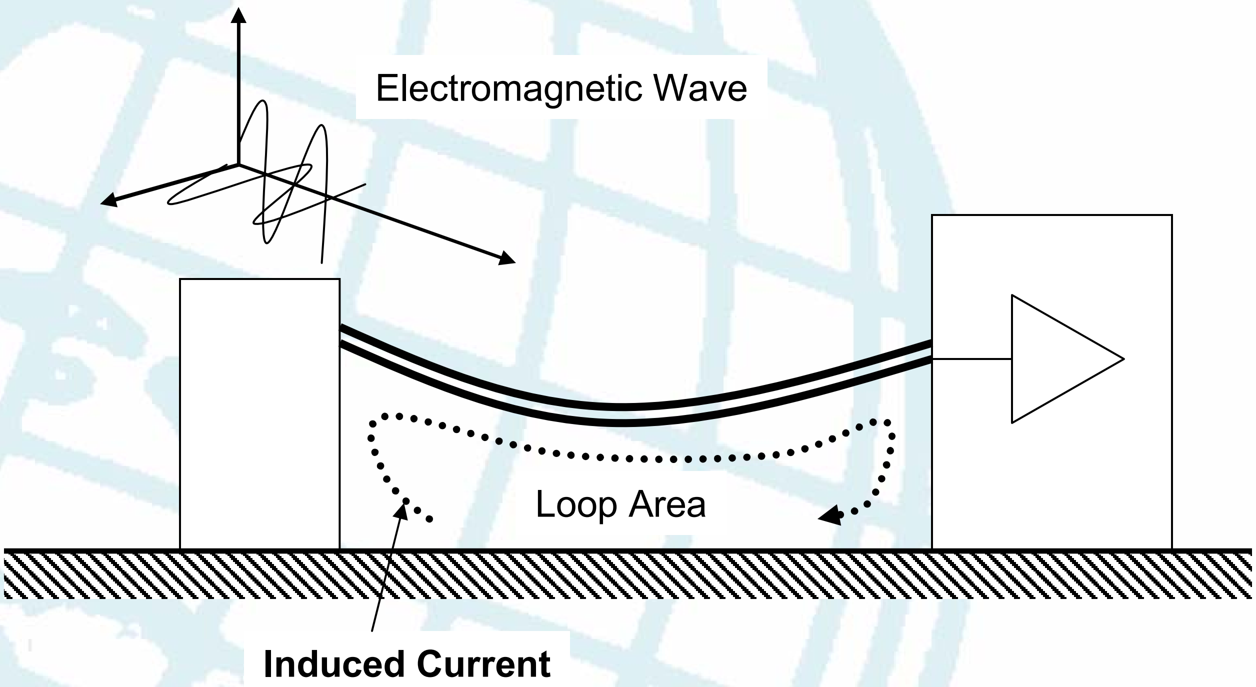
Power lead coupling causes the mains to act as a victim to unit noise as well as a source coupling external noise to the unit.

Cable to Cable Coupling - Crosstalk



Cables in close proximity couple signals via mutual inductance and mutual capacitance. The undesired emissions can appear as both conducted common mode and differential mode noise.

Field to Cable Coupling



Coupling proportional to: E/H Field, Loop Area, Frequency

Voltage Induced – Circuit Loop

Plane wave coupling - Voltage induced (V_i) into circuit loop:

$$V_i = E_o h \sqrt{2\left[1-\cos\left(\frac{\pi L f_{MHz}}{150}\right)\right]}$$

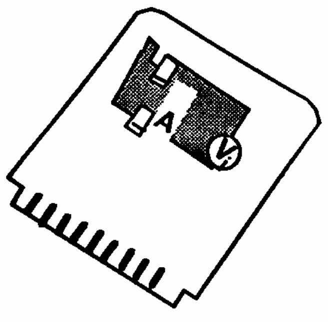
$$V_i = B_o h\left(3X10^8\right)\sqrt{2\left[1-\cos\left(\frac{\pi L f_{MHz}}{150}\right)\right]}$$

$$Max V_i = 2E_o h$$

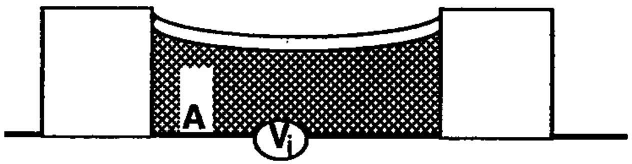
$$Max V_i = 2B_o h\left(3X10^8\right)$$

E_o = Interference amplitude (V/m)
h = loop height
L= loop length
B_o=Interference amplitude (Tesla)

Circuit Loops



PCB - Level Circuit Loop



System - Level Circuit Loop

$$\frac{V_i}{E_o}(dB) = 20\log[h] + 10\log[2(1-\cos\beta l)]dB_{meter}$$

$$\frac{V_i}{B_o}(dB) = 89.5 + 20\log[h] + 10\log[2(1-\cos\beta l)]dB_{volts/gauss}$$

V_i=Induced voltage
E_o=ambient electric field amplitude
B_o=ambient magnetic flux density
h=loop height in meters
l=loop length in meters
$\beta=2\pi/\lambda$

Maximum coupling occurs when cos β*l* = -1 and zero coupling when cos β*l*=+1. Frequencies of maxima are given by:

$$f_{MHz}^{\max} = (2n-1)\frac{150}{l} \Rightarrow n = 1,2,3\ldots$$

Voltage Induced – Circuit Loop

- Coupling into a 1 cm^2 square loop
  - $V_i = E_o h SQRT[2(1-\cos(\pi L f_{MHz}/150))]$ V
    - h=1cm=0.01m; L=1cm-0.01m
  - $V_{i(volt)} = 2.09E\text{-}3 * E_o$ (f=1GHz, λ=30cm)
  - $V_i/E_o = 2.09_{mV/V/m}$ (f=1GHz, λ=30cm)
  - $V_i/E_o = 17.32_{mV/V/m}$ (f=10GHz, λ=3cm)
  - $V_i/E_o = 20_{mV/V/m}$ (f=15GHz, λ=2cm) (Max)
  - $V_i/E_o = 17.32_{mV/V/m}$ (f=100GHz, λ=0.3cm)
- For example: @15GHz with a 100V/m field the V_i would be 2V – a significant value for a 3.3V logic

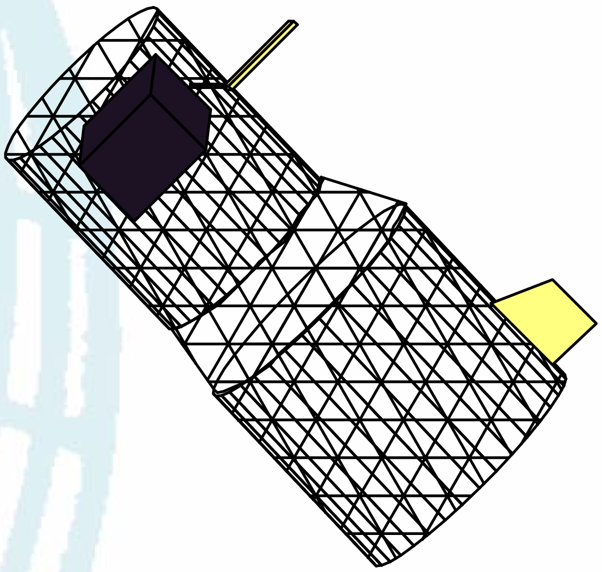
Field Strength at Victim

Friis transmission formula $E_{v/m} = \sqrt{30 * P_t * G_t}$

Received RF Field Strength (from Antenna Outputs)		
Transmit Frequency	2000	MHz
Transmit Power	5	W
Antenna Gain (estimated)	1.00	dBi
Antenna Cable Loss (worst case assumption)	1.00	dB
Shield Attenuation (estimated)	60.00	dB
Transmit Path Gain (converted (antenna gain - cable loss - shield attenuation))	0.000	(unitless)
Distance (Antenna to Victim Equipment) (estimated)	1.0	meters
Far-field boundary distance	0.024	meters
Field Strength (Including shield attenuation)	0.01	V/m
Field Strength (Including shield attenuation)	81.8	dBuV/m
Field Strength (Excluding shield attenuation)	13.18	V/m
Field Strength (Excluding shield attenuation)	142.4	dBuV/m

Out-of-band Interference

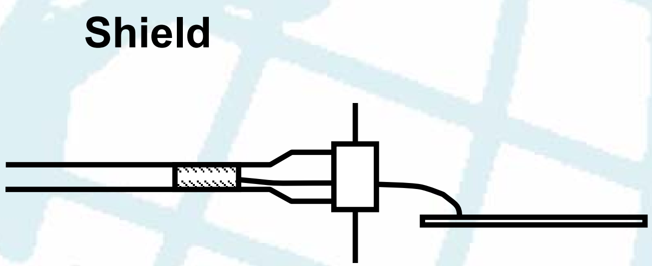
- Field strength at source
  - 82dBμV/m
  - 142dBμV/m
- Out-of-band filter attenuation
  - 80dB
- Receive sensitivity
  - -115dBm (-8dBμV)
- Sensitivity degradation
  - 9dB
  - 69dB



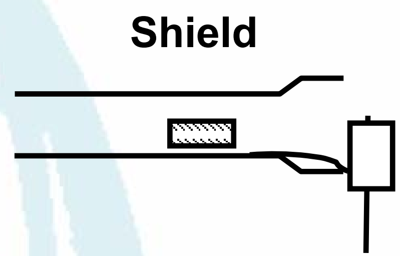
Cables - Significant

- Cables can be large contributors to interference problems
  - Power cables
  - Grounding wires
  - Patient cables
  - Data cables
  - Control harnesses
  - Structures!
- Cables function as the coupling path for emitters and victims
- Cables are often an imposed element of the system
- Cables handle high level and sensitive signals
- Cables support intra- and inter-system interfaces

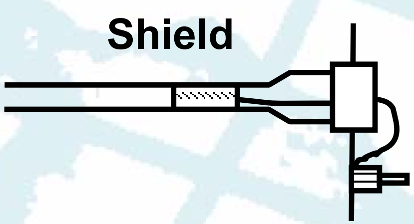
Shielding Design - Cables



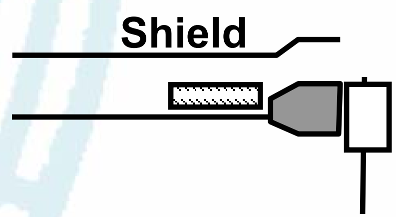
Worst:
Shield Ground to PCB



Inadequate:
Shield Ground Pigtail

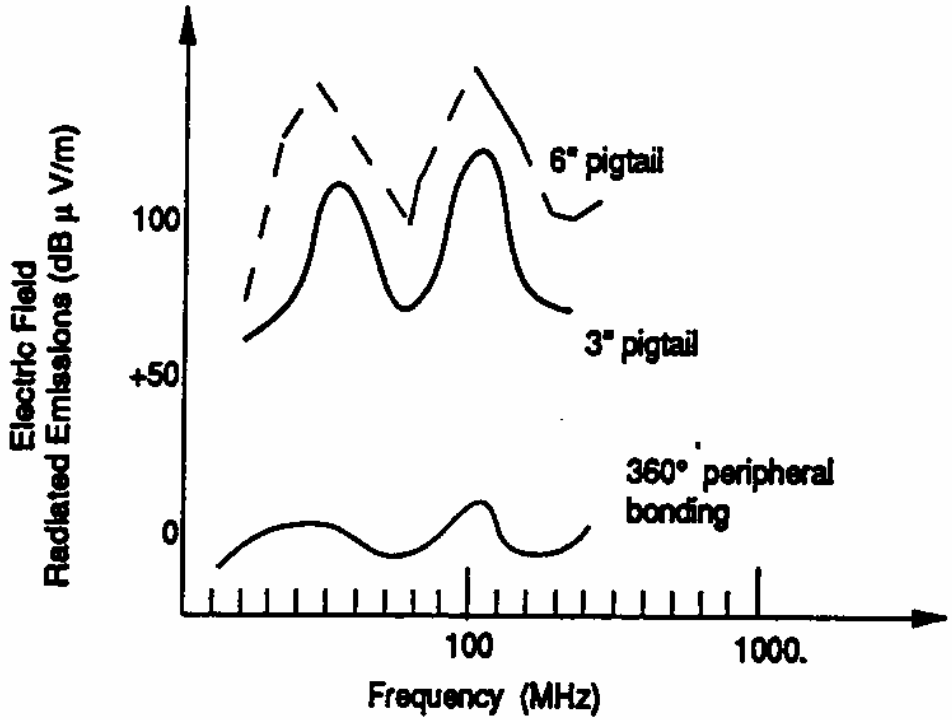


Bad:
Shield Ground Internal to Case



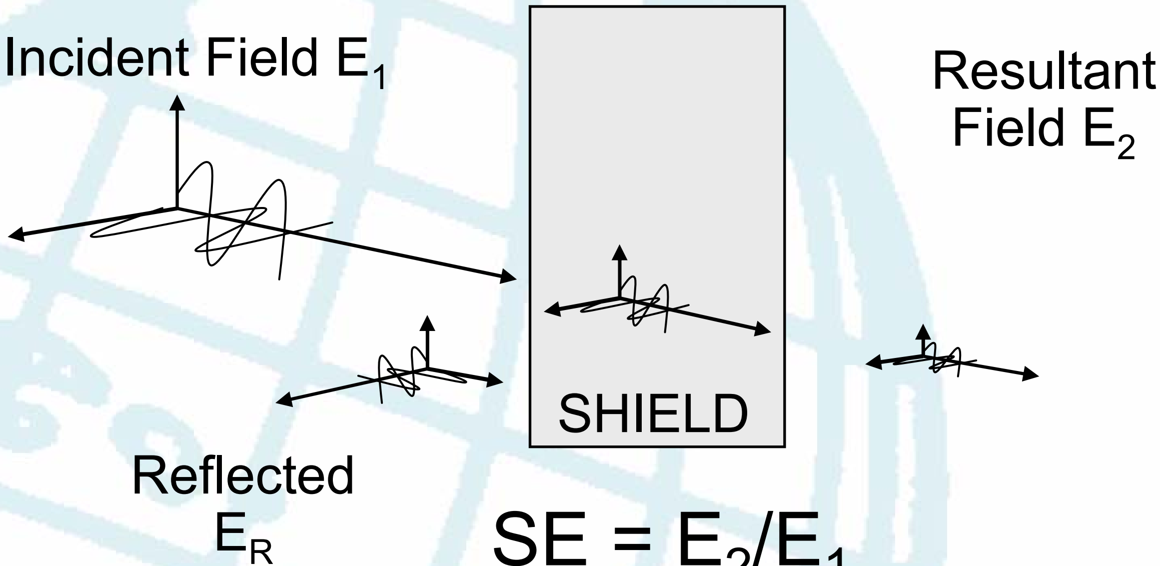
Best:
Terminate 360º to Backshell

Shield Termination



Radiated emissions from a rigid coaxial transmission line with various outer conductor terminated conditions. Line excitation is 0 dBm into a 50Ω load

Shielding Concept



$$SE = E_2/E_1 \text{ (dB)}$$

Shielding effectiveness is a combination of reflection, absorption, and re-reflection.

Shielding Effectiveness - Approximation

$$R_{E(dB)} = 322 + 10\log\left(\frac{\sigma}{\mu * R^2_{(meters)} * f^3_{(Hz)}}\right)$$

$$R_{H(dB)} = 14.5 + 10\log\left(\frac{f_{(Hz)} * \sigma * R^2_{(meters)}}{\mu}\right)$$

$$R_{P(dB)} = 168 + 10\log\left(\frac{\sigma}{\mu} * f_{(Hz)}\right)$$

Plane wave occurs when E to H wave impedance ratio = 377

$$f_{(MHz)} > 300 / 2\pi R_{(meters)}$$

$$A_{(dB)} = k * t * \sqrt{f_{(Hz)} * \mu * \sigma}$$

σ=conductivity
μ=permeability
f=frequency
R=source to shield
t=thickness

k = 3.4 for t in inches and k = 134 for t in meters
If frequency is changed to MHz then inches become mils and meters become mm

Shielding Apertures

- Aperture shielding sum of absorption and reflection
  - Absorption
    - Circular aperture

$$SE_{(dB)} = 31.95\frac{t_{(in)}}{d_{(in)}}\sqrt{1-\left(\frac{df_{(MHz)}}{6920}\right)^2}$$

    - Rectangular aperture

$$SE_{(dB)} = 27.3\frac{t_{(in)}}{d_{(in)}}\sqrt{1-\left(\frac{df_{(MHz)}}{5910}\right)^2}$$

d=diameter
t=thickness

For most applications the t (thickness) to d (diameter or longest side) ratio is small and absorption becomes insignificant

  - Reflection (for $f_{(GHz)} < 17.5/a_{(cm)}$)
    - $SE_{(dB)} = 110 - 10 \log (a^4 * N)$ (a=opening in cm, N= # of openings)
    - $SE_{(dB)} = 94 - 10 \log (a^4 * N)$ (a=opening in inches)
    - for $f_{(GHz)} > 17.5/a_{(cm)}$ reflected SE is insignificant

Electromagnetic Compatibility – The Solutions

- Identify: Source(s) > Coupling Path(s) > Victim(s)
  - CE, CS, RE, RS
  - Common impedance, E/H Field Coupling, Crosstalk
  - Apply: Analysis, Measurements, "Experience"
- Select applicable "Fix" approach(es)
  - Component selection: "Quiet" logic families
  - Grounding: PCB, Power, Signal, System, Chassis
  - Shielding: Enclosures, Cables, Circuit Isolation
  - Filtering: CM/DM, Transient Suppressors
  - Layout: Component/Subassembly location, Interconnection routing/termination, Spatial orientation

Contacts

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